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AFCRL-63-495

FINAL REPORT

MEASUREMENT OF INFRARED SPECTRAL COMPONENTS FLOWING UPWARD AND DOWNWARD IN THE ATMOSPHERE

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by
ROBERT C. WHITE

THE JOHNS HOPKINS UNIVERSITY
LABORATORY OF ASTROPHYSICS AND PHYSICAL METEOROLOGY
Baltimore, Maryland 21218

APRIL 19, 1963

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Project No. 5043
Task No. 79708
Contract No. AF 19(604)-6174

Research reported in this document sponsored by:

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
OFFICE OF AEROSPACE RESEARCH
UNITED STATES AIR FORCE
BEDFORD, MASSACHUSETTS

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PREFACE

This report gives the results of the effort to measure spectral components of infrared radiation in the atmosphere as a function of height. The work falls short of our expectations because of difficulties in getting a balloon to carry our equipment aloft at a slow enough rate. The slow rate has been necessary in order for us to get more observations during ascent and descent, and fewer observations at altitude.

The tactical moves to avoid such frustrations, in the future, seem to us to fall into two categories: First, to make the equipment operate faster, so that the high rate of ascent of the balloons does not compromise the desired results; and, second, to use airplanes which can fly above and below the tropopause at constant altitudes for a protracted time. Equipment for response in the first category is in hand. The use of an airplane would involve major changes in the equipment.

We believe that a basic need in physical meteorology is the measurement of spectral components of infrared radiation flowing upward and downward in the atmosphere, measured at several stations over the earth at all seasons of the year. Such observations

would contribute greatly to our knowledge of radiative heat transfer in the atmosphere by the infrared, and this heat transfer is important because it is, in turn, the major factor in producing the atmospheric circulation.

John Strong

ABSTRACT

Raw data of a balloon flight to determine the spectral components of infrared radiation, flowing up and downward in the atmosphere, has been previously reported.* This report presents the analysis of that data, giving the flux quantitatively, in the infrared bands (each one micron wide) extending from 8 to 25 microns. Flux upward and downward at various altitudes is given.

*Robert C. White. Report on Raw Data of the Balloon Flight of August 21-22, 1961. Progress Report, AF 19(604)-7490, [Nov. 1961].

This report is concerned with bolometric records of earth and sky radiations in the range 8 μ to 25 μ made from a balloon in August 1961.

The balloon carrying the spectrometer was launched from White Sands Missile Range, New Mexico, at 11:27 p.m. on August 21 and reached a maximum altitude of 83,500 ft. Records were made continuously during the ascent and until the balloon had descended to 60,500 ft., which level was reached at approximately 5 a.m. the following morning. During this time the balloon drifted about 100 miles to the west. (See Figs. 1 and 2 for trajectory and profile.)

The spectrometer, by means of a cam-driven mirror, looked in turn toward the sky, toward the ground, into one cavity kept at 0°C by melting ice (called WET), and into another cavity containing solid carbon dioxide (called DRY). The temperature of the latter was assumed to be the equilibrium temperature of solid carbon dioxide at the pressure corresponding to the altitude at the moment. The sequence followed was SKY, WET, DRY,

GROUND, DRY, WET, and repeat. (See Fig. 3 for a simplified diagram of the spectrometer.)

Incoming radiation from the sources, after being chopped, was focused upon the entrance slit. It was then collimated and directed upon a mosaic of four gratings. The latter was rocked at a very slow speed by a worm drive provided with a reversing switch. Three exit slits were provided and so arranged that the wavelengths were swept over them. Covering the first exit slit was a filter consisting of a 0.1 mm layer of coated indium antimonide on a rock salt window. This filter effectively blocked all radiation below 8 μ. Covering the second window was a filter of Irtran blocking radiation beyond 10 μ. Associated with the third exit slit were two reflectors of polished crystal magnesium oxide so arranged that radiation passing through the slit was reflected from them in succession before continuing through the optical system. This eliminated wavelengths below 13 μ. Energy from each slit fell upon an ellipsoidal mirror which focused it upon a corresponding element of a three-element thermopile. The output of each element, after amplification, was recorded on film by a reflecting galvanometer and lamp.

This report makes use of records from the first slit (InSb) for wavelengths 8 μ to 14 μ and from the third slit (MgO) for wavelengths 14 μ to 25 μ. The records corresponding to each of these two slits were plotted as deflections due to SKY (looking up), GROUND (looking down), WET, and DRY, respectively. (Actually each record shows the difference in radiation alternately received from that particular source and from the chopper blade.) Since during one complete scan from 8 μ to 25 μ the spectrometer looked many times in each of the four directions, a curve plotted for each direction (SKY, GROUND, WET, DRY) can be considered as being obtained simultaneously with the others. See Fig. 4 for typical curves drawn from raw data. By subtracting one curve from another, the effect of the chopper blade's radiation is cancelled. It is assumed that the chopper blade (about 20 inches in diameter) had sufficient heat capacity to prevent a significant change in its temperature during one sequence of SKY, WET, DRY, GROUND, DRY, WET.

The difference between a WET and a corresponding DRY curve can be considered as the system's response to the difference between the radiation from two blackbodies at known temperatures, thus providing for calibration of the WET-SKY and WET-GROUND curves.

The area under each curve was divided into vertical bands, 1 micron wide, extending from 8 μ to 9 μ, 9 μ to 10 μ, etc. to 25 μ. From the measured area of a band under the WET-DRY (W-D) curve and the known radiation difference in watts/cm^2/micron at this wavelength for blackbodies at these temperatures, a value of watts/cm^2 per unit measured area for each band for each WET-DRY curve was obtained. The product of the area of each band under the WET-SKY (W-S) and WET-GROUND (W-G) curves by the appropriate value (obtained as described above) gave the flux received in that band. The flux difference corresponding to (G-S) was obtained by subtracting (W-G) from (W-S) for each band.

In Figs. 5 to 11 the results are plotted as "brightness" differences, (B_W-B_S) and (B_W-B_G), versus wavelength for each of the complete scans. Fig. 12 shows the altitude at the beginning and end of each scan.

Figs. 13 to 20 show the integrated flux for each micron band as a function of altitude. In the same figure in each case is a plot of galvanometer deflections corresponding to W-D radiations. This latter plot shows variations of our calibration.

Except for the change in temperature of the dry ice with altitude the deflections should have been constant.

We have not yet determined the cause of the variations observed. The rather steady decline during descent may have been caused by decay of amplifier battery voltages. Erratic variations may be due to accumulation of frost in the mouth of the dry ice cavity. It was intended to remove this by a brush operated by the sequence cam. Incomplete cleaning may have occurred on some cycles. We are planning to avoid this on future flights by using a thermostatically controlled blackbody at such a temperature that frost will not form.

Variations might have been caused also by a change in temperature of the chopper blade. If it decreased to 0°C, a subsequent change, either above or below 0°C, would give the same signal relative to the wet source. This would mean an uncertainty in the WET record. Although this could account for a slow drift in calibration, it surely cannot account for the rapid variations shown in the plots.

Values of $(B_G - B_S)\, d\lambda$ integrated from 8 μ to 25 μ over each scan are plotted versus altitude in Fig. 21 and versus ambient pressure in Fig. 22.

Except for the change in temperature of the dry ice with altitude the deflections should have been constant.

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Values of $(B_G - B_S)\, d\lambda$ integrated from 8 μ to 25 μ over each scan are plotted versus altitude in Fig. 21 and versus ambient pressure in Fig. 22.

The value of $\int_{8}^{25} (B_G - B_S)\, d\lambda$

at any given altitude represents the net efflux of energy in watts/cm^2 (over this range) at that level. The difference between two such values, at two different levels, represents the net flux leaving the layer of air between these levels.

An estimate of the radiative cooling of the air at relatively low levels can be obtained from the slope of the curve in Fig. 22.

$\frac{\partial \Phi}{\partial p}$ for lower levels equals

9.6×10^{-9} watts/cm^2/millibar

Then $\frac{dT}{dt} = \frac{g}{4.19 C_p} \times 9.6 \times 10^{-9}$

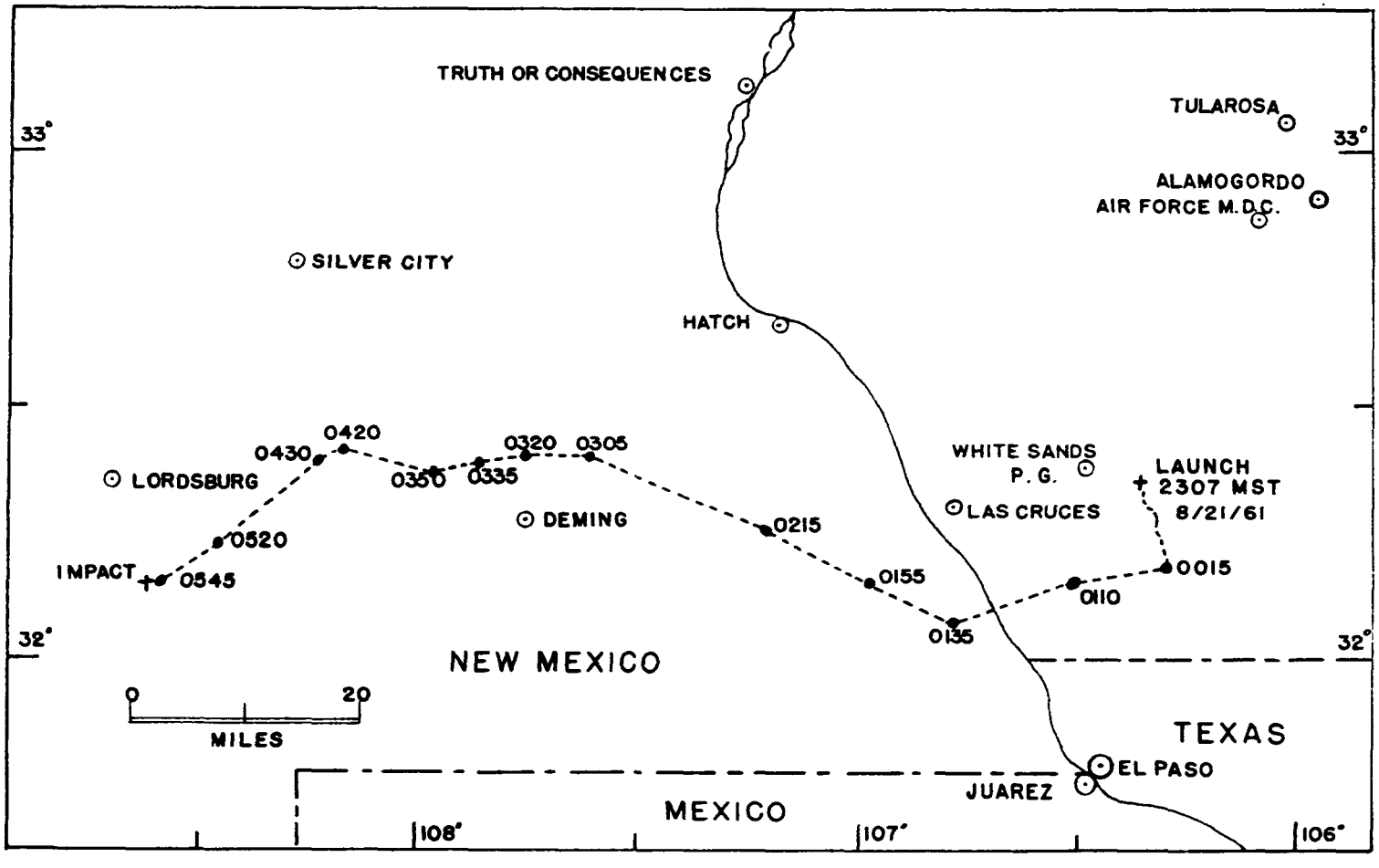
$= 9.4 \times 10^{-6}$ degrees/sec

or 0.81 degrees/day

Acknowledgments

The Johns Hopkins field group consisted of Dr. John Strong and Messrs. Thomas Green, John McClellan, Walton Webb and Robert White.

The group acknowledges the effectiveness of the flight crew and management at the Balloon Branch of the Air Force Missile Development Center at Holloman Air Force Base.



TRAJECTORY

FIG. 1

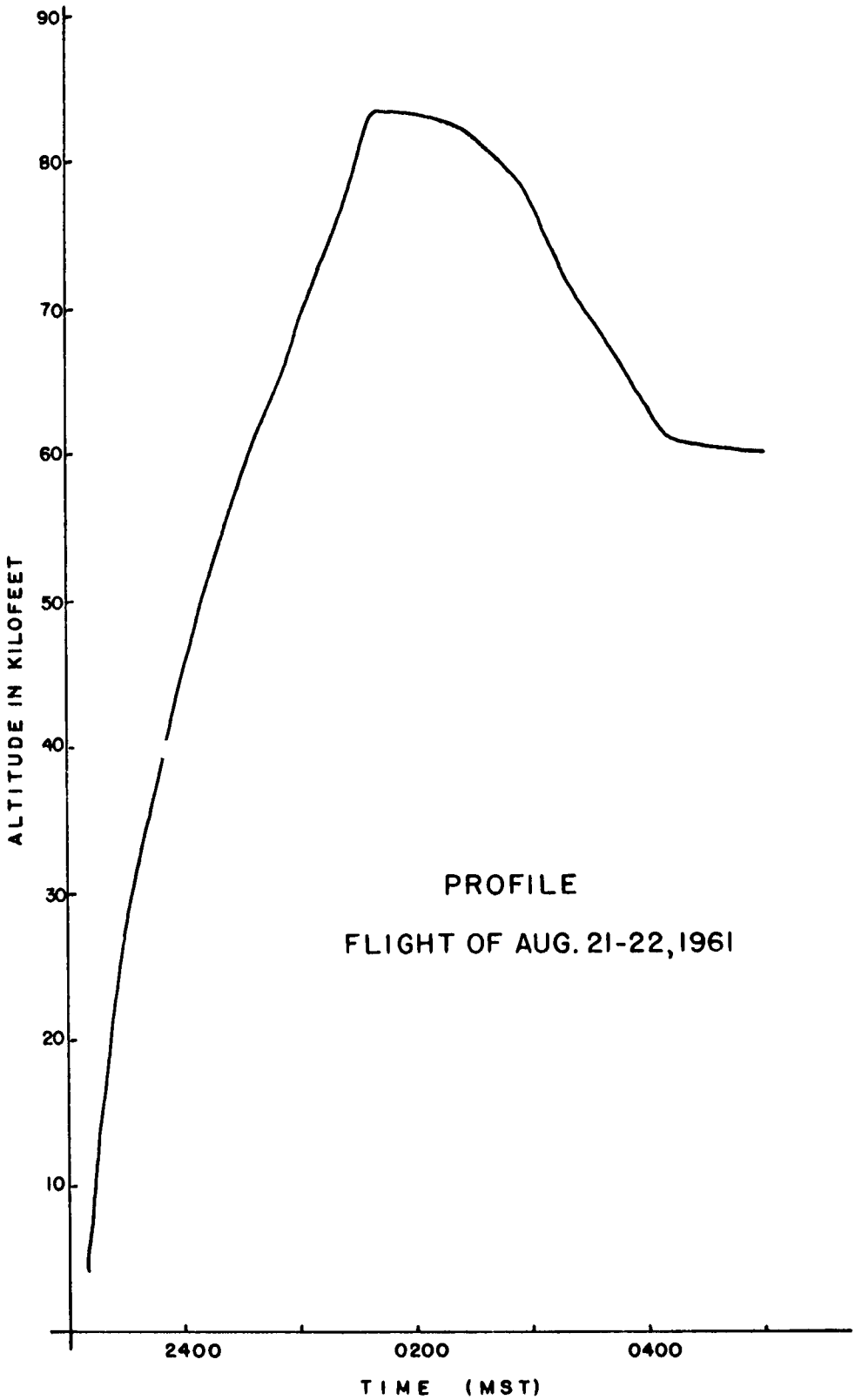
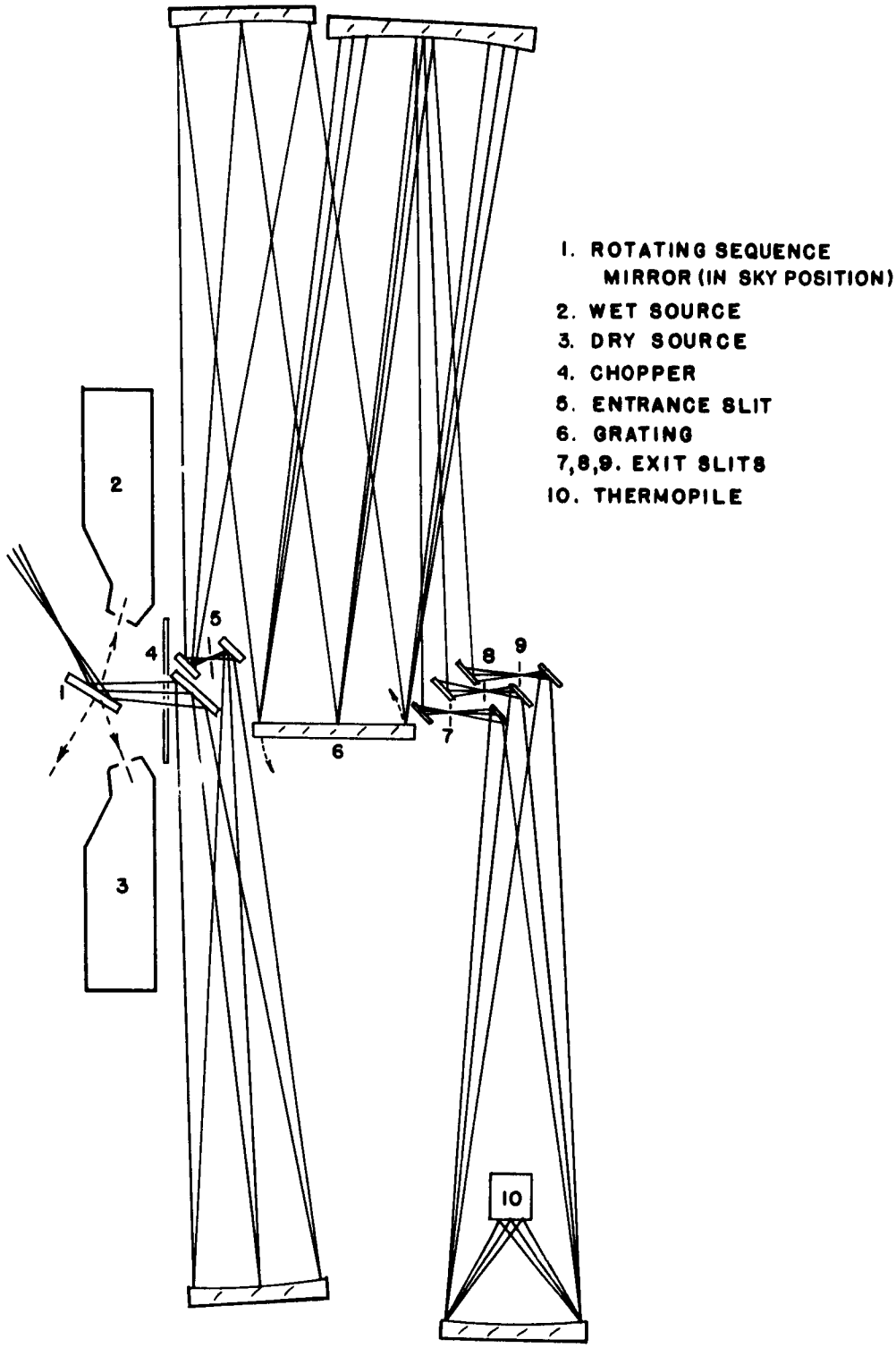

90
80
70
60
50
40
30
20
10
ALTITUDE IN KILOFEET
PROFILE
FLIGHT OF AUG. 21-22, 1961
2400
0200
0400
TIME (MST)

FIG. 2



SPECTROMETER
(OPTICAL LAYOUT)

FIG·3

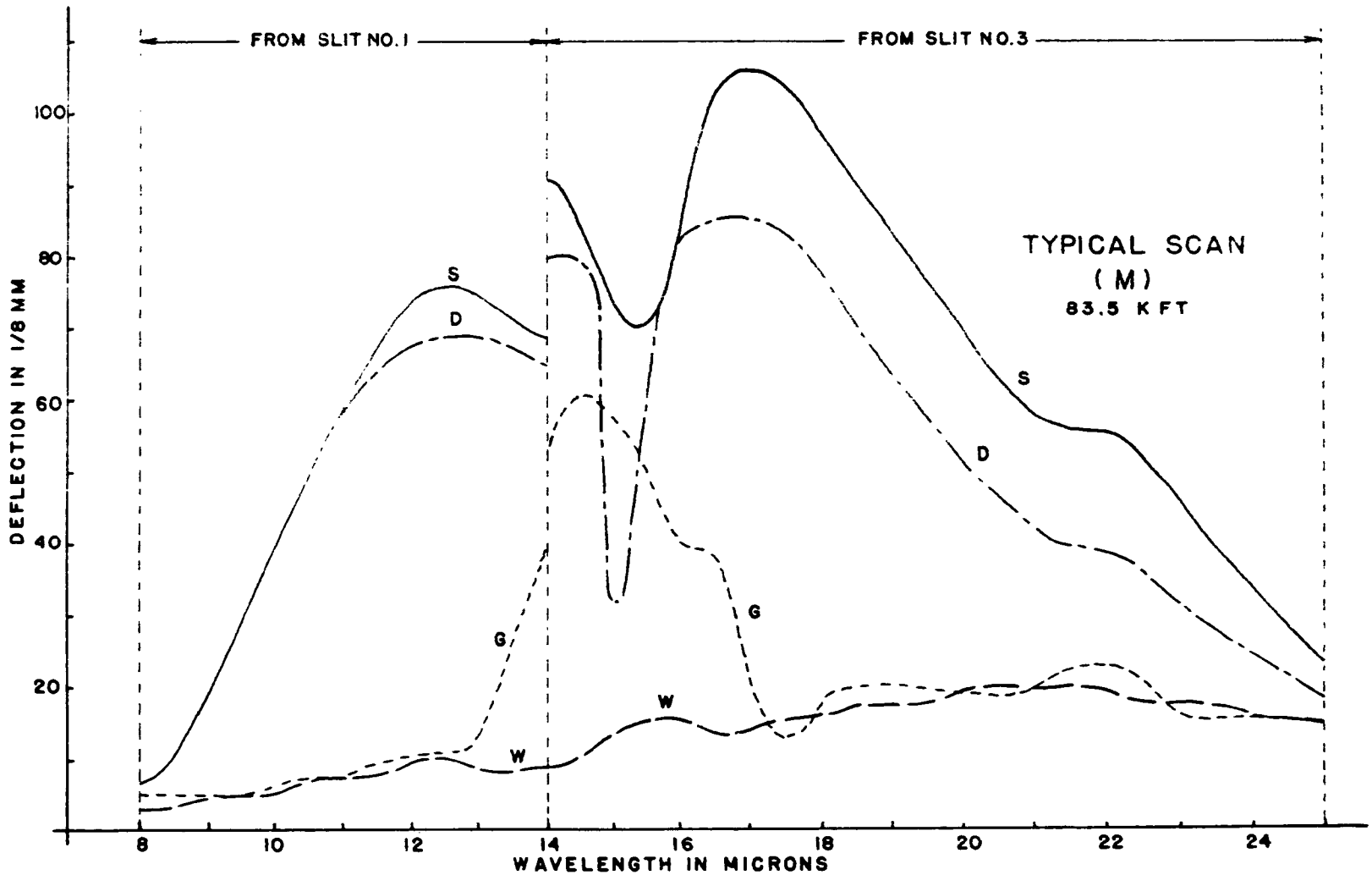

FROM SLIT NO. 1
FROM SLIT NO. 3
TYPICAL SCAN
(M)
83.5 K FT
S
D
G
W
DEFLECTION IN 1/8 MM
WAVELENGTH IN MICRONS
100
80
60
40
20
8
10
12
14
16
18
20
22
24

FIG. 4

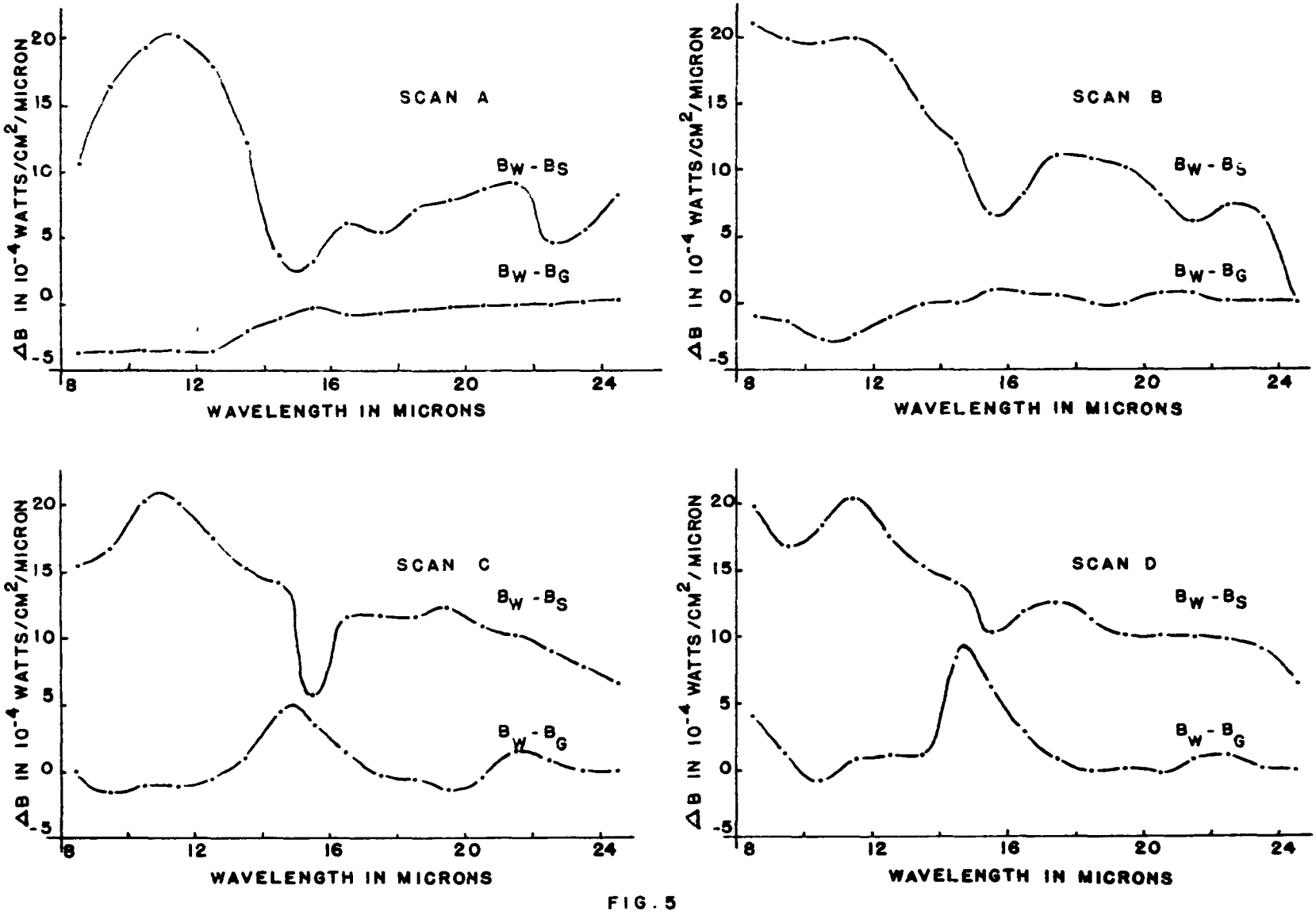
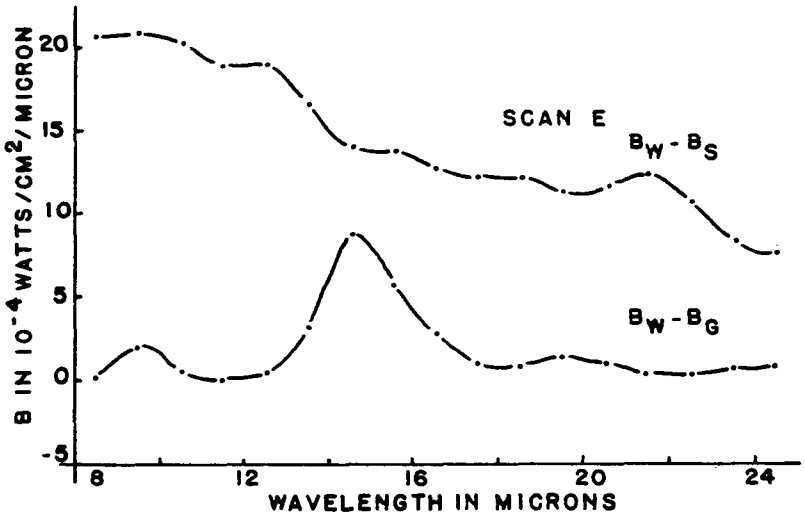
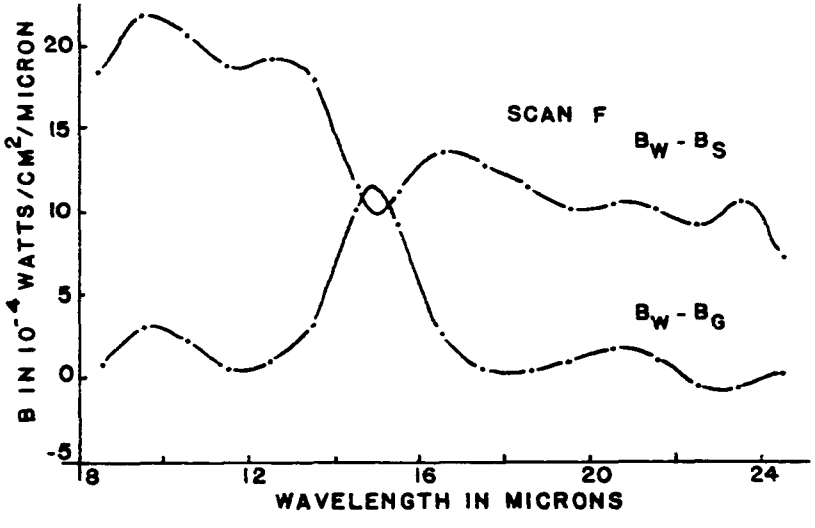
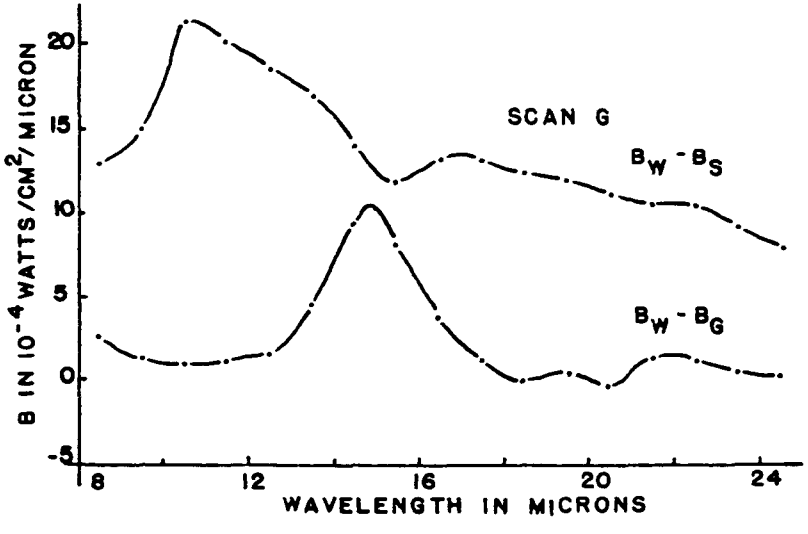

SCAN A
SCAN B
SCAN C
SCAN D
$B_W - B_S$
$B_W - B_G$
ΔB IN 10^{-4} WATTS/CM^2/MICRON
WAVELENGTH IN MICRONS
20
15
10
5
0
-5
8
12
16
20
24

FIG. 5


SCAN E
$B_W - B_S$
$B_W - B_G$
B IN 10^{-4} WATTS/CM^2/ MICRON
WAVELENGTH IN MICRONS


SCAN F
$B_W - B_S$
$B_W - B_G$
B IN 10^{-4} WATTS/CM^2/MICRON
WAVELENGTH IN MICRONS


SCAN G
$B_W - B_S$
$B_W - B_G$
B IN 10^{-4} WATTS/CM^2/ MICRON
WAVELENGTH IN MICRONS

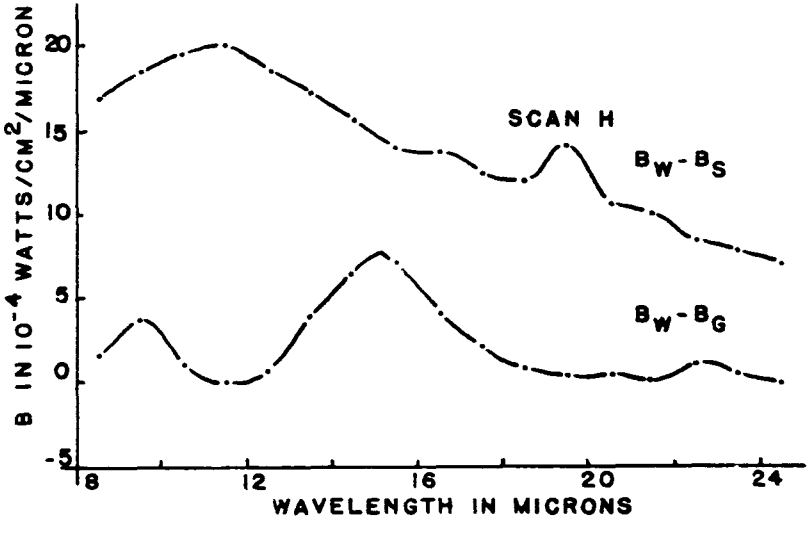

SCAN H
$B_W - B_S$
$B_W - B_G$
B IN 10^{-4} WATTS/CM^2/MICRON
WAVELENGTH IN MICRONS

FIG. 6

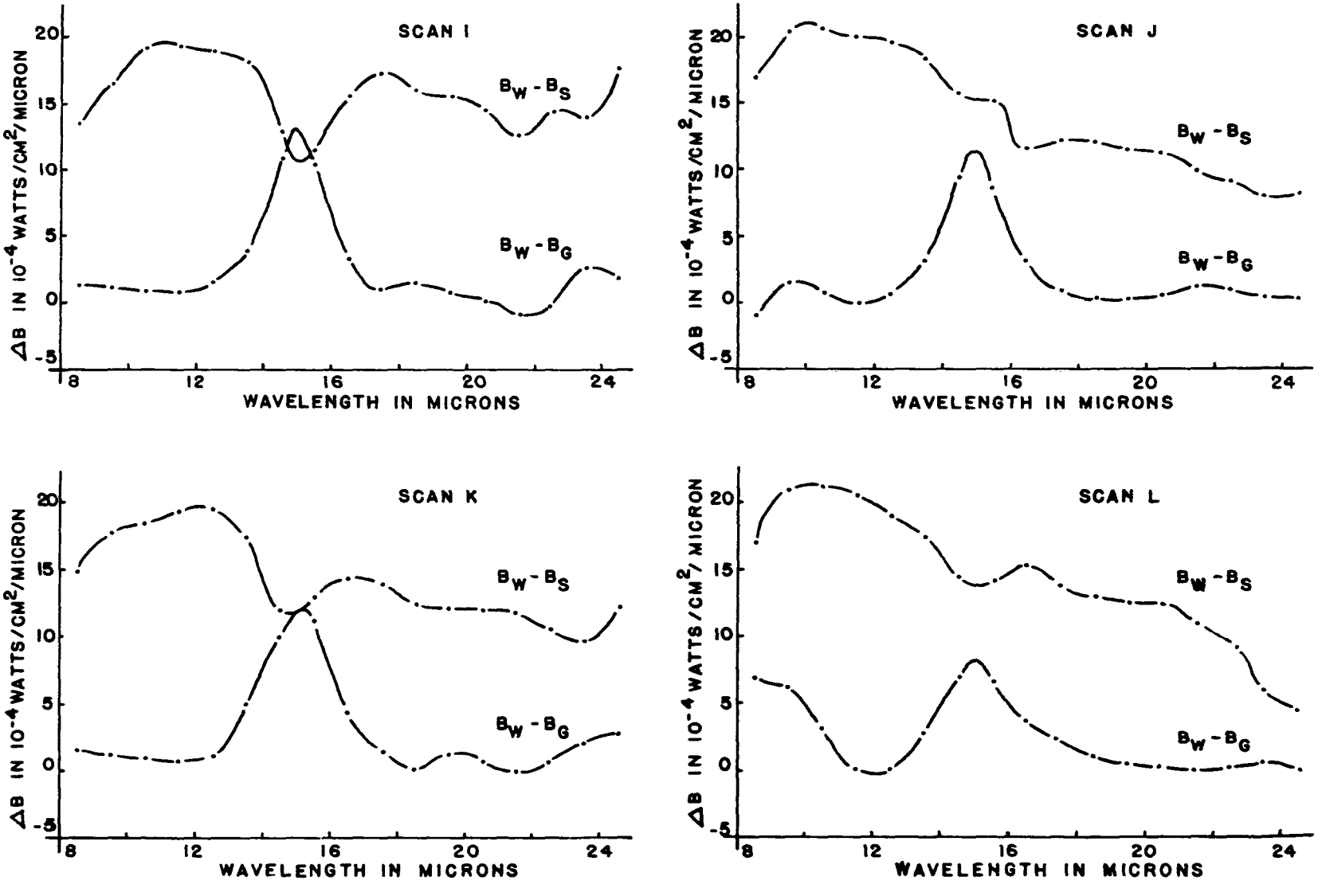
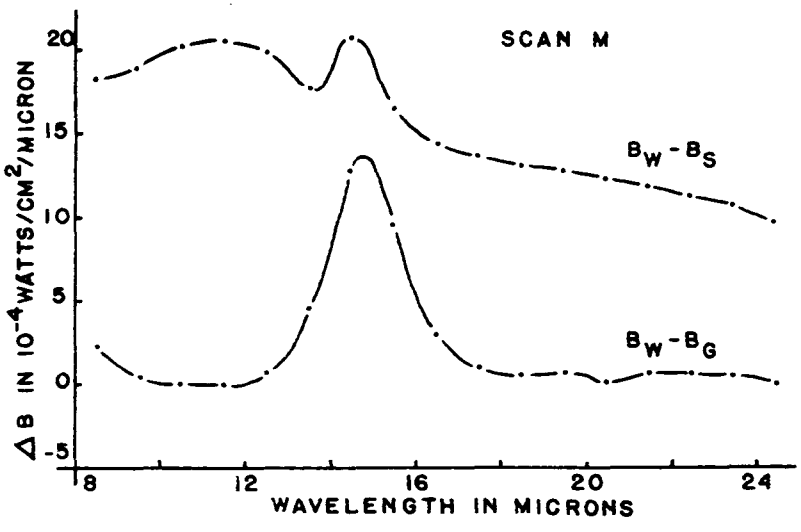
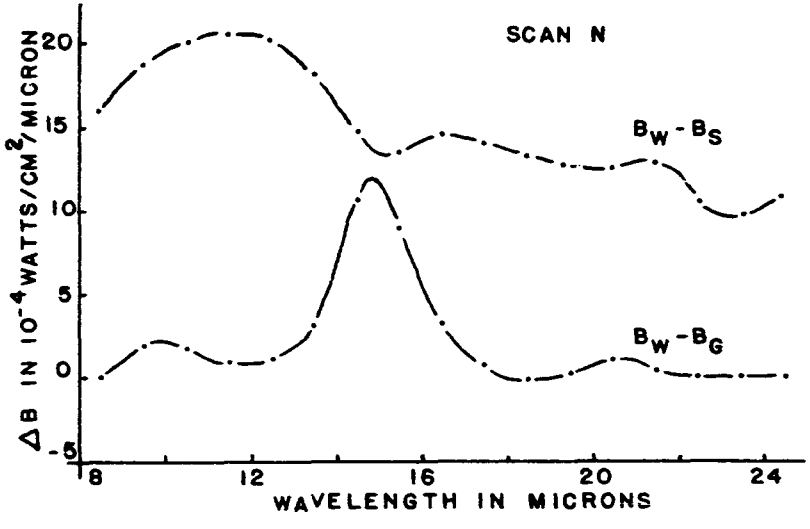
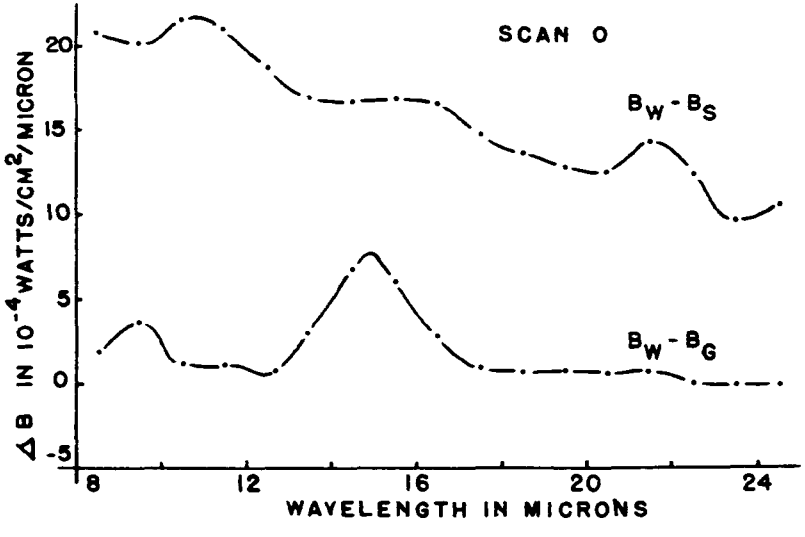

SCAN I
SCAN J
SCAN K
SCAN L
$B_W - B_S$
$B_W - B_G$
ΔB IN 10^{-4} WATTS/CM^2/MICRON
WAVELENGTH IN MICRONS
20
15
10
5
0
-5
8
12
16
20
24

FIG. 7


SCAN M
$B_W - B_S$
$B_W - B_G$
ΔB IN 10^{-4} WATTS/CM^2/MICRON
WAVELENGTH IN MICRONS
20
15
10
5
0
-5
8
12
16
20
24


SCAN N
$B_W - B_S$
$B_W - B_G$
ΔB IN 10^{-4} WATTS/CM^2/MICRON
WAVELENGTH IN MICRONS
20
15
10
5
0
-5
8
12
16
20
24


SCAN O
$B_W - B_S$
$B_W - B_G$
ΔB IN 10^{-4} WATTS/CM^2/MICRON
WAVELENGTH IN MICRONS
20
15
10
5
0
-5
8
12
16
20
24

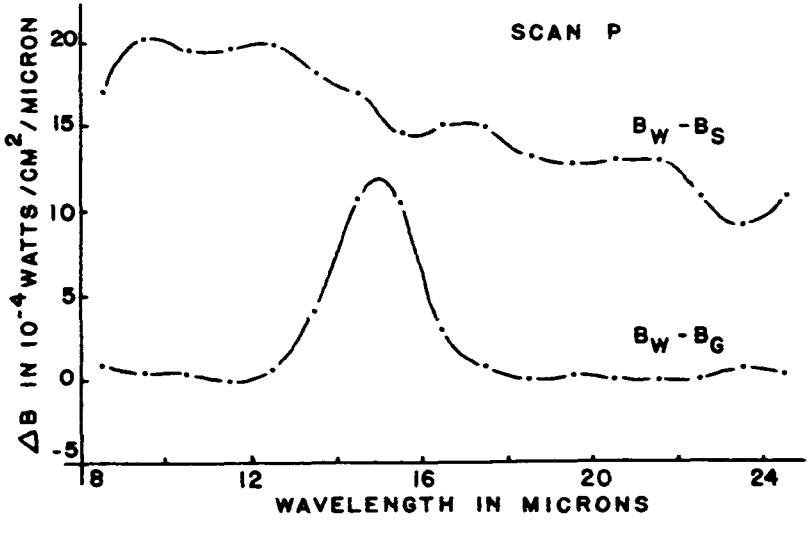

SCAN P
$B_W - B_S$
$B_W - B_G$
ΔB IN 10^{-4} WATTS/CM^2/MICRON
WAVELENGTH IN MICRONS
20
15
10
5
0
-5
8
12
16
20
24

FIG. 8

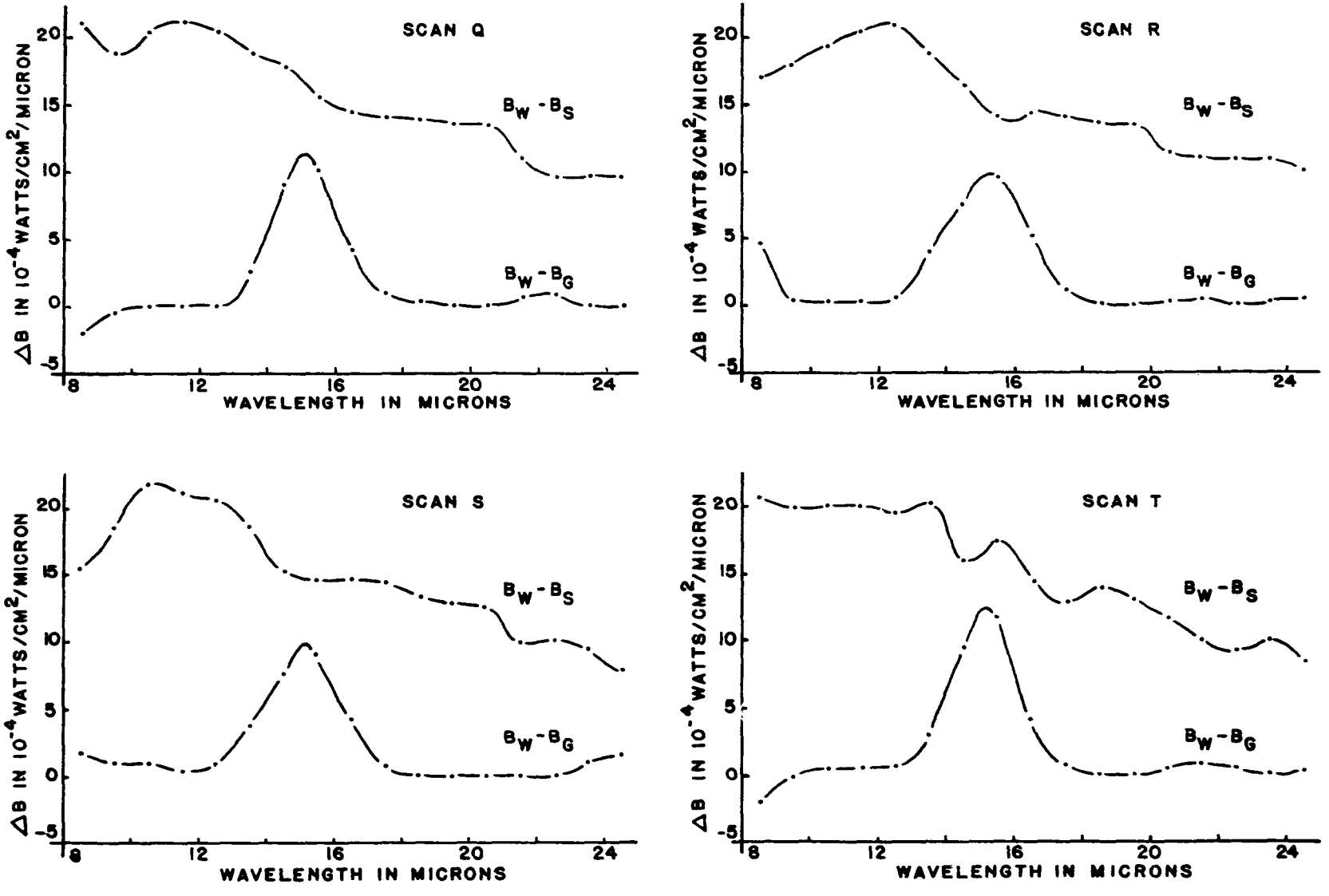

SCAN Q
SCAN R
SCAN S
SCAN T
$B_W - B_S$
$B_W - B_G$
ΔB IN 10^{-4} WATTS/CM^2/MICRON
WAVELENGTH IN MICRONS
20
15
10
5
0
-5
8
12
16
20
24

FIG. 9

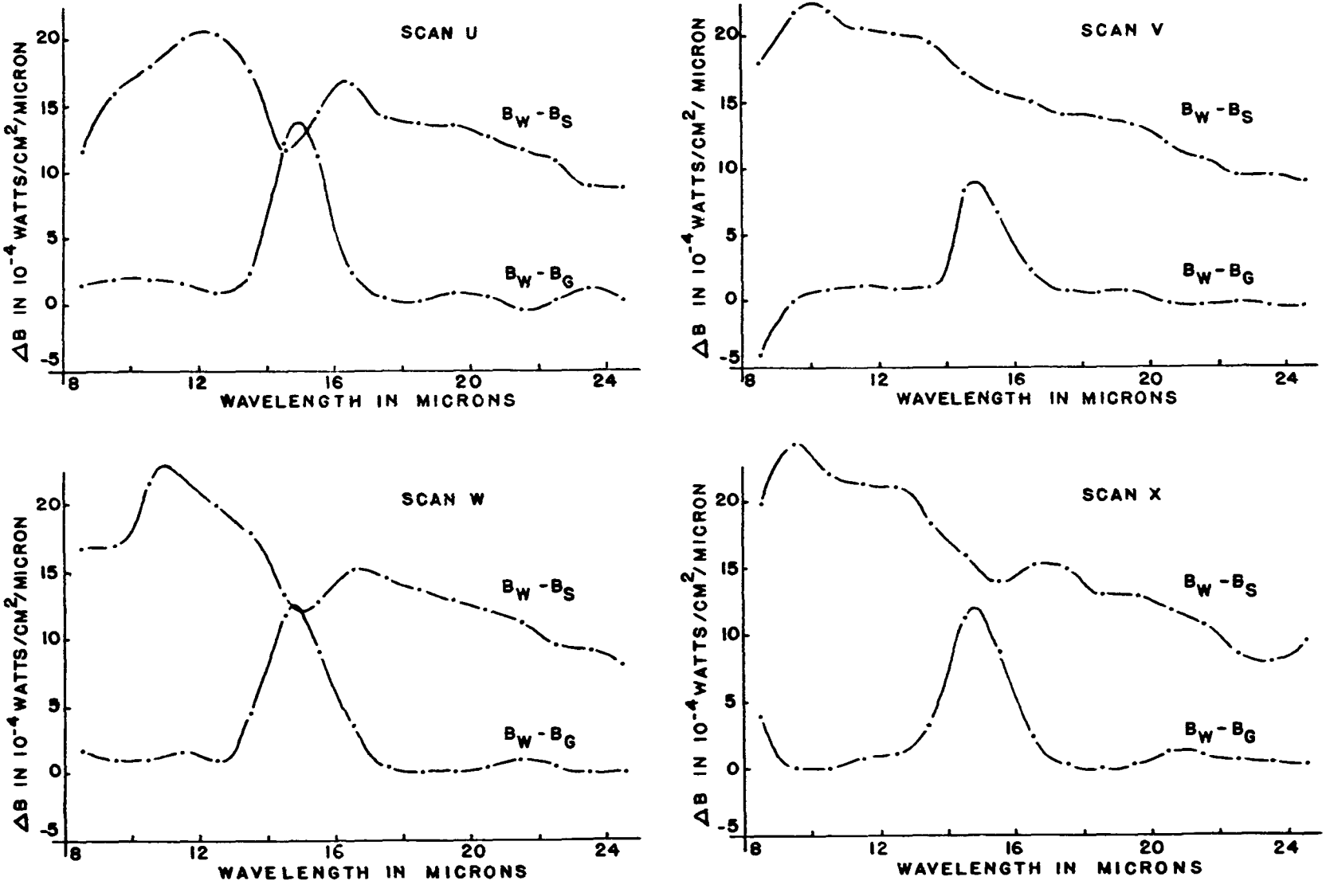

SCAN U
SCAN V
SCAN W
SCAN X
$B_W - B_S$
$B_W - B_G$
ΔB IN 10^{-4} WATTS/CM^2/MICRON
WAVELENGTH IN MICRONS
20
15
10
5
0
-5
8
12
16
20
24

FIG. 10

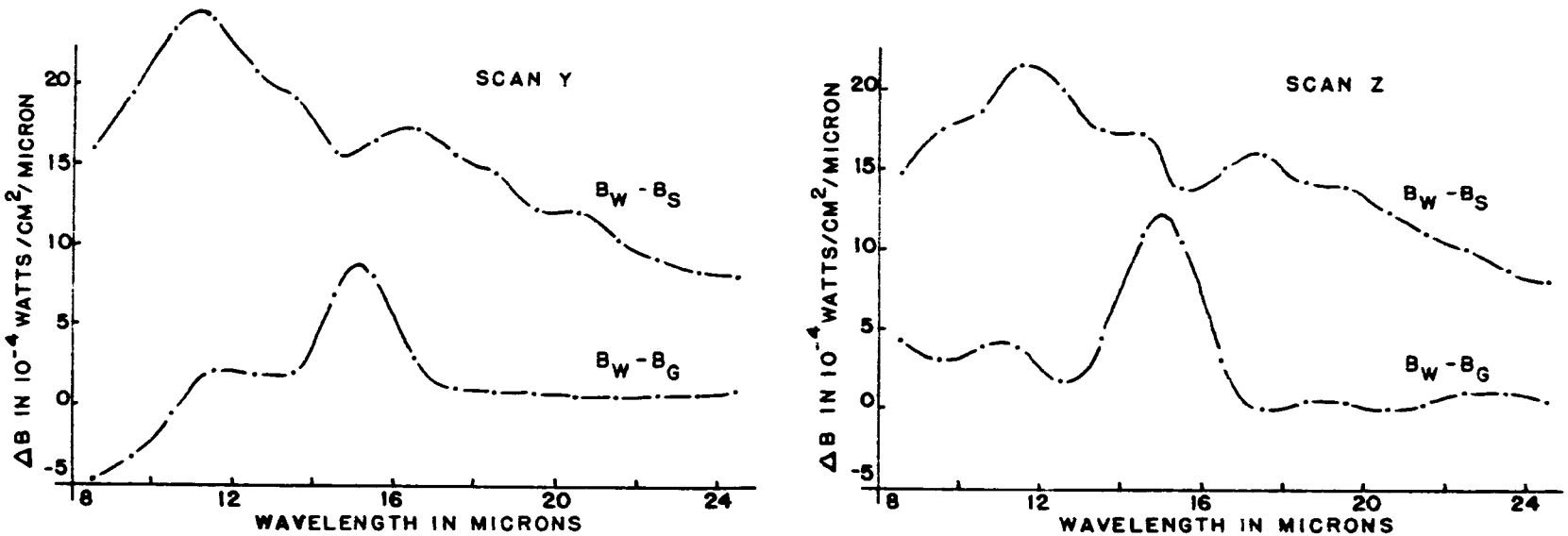

SCAN Y
SCAN Z
$B_W - B_S$
$B_W - B_G$
ΔB IN 10^{-4} WATTS/CM^2/MICRON
WAVELENGTH IN MICRONS
20
15
10
5
0
-5
8
12
16
20
24

FIG. 11

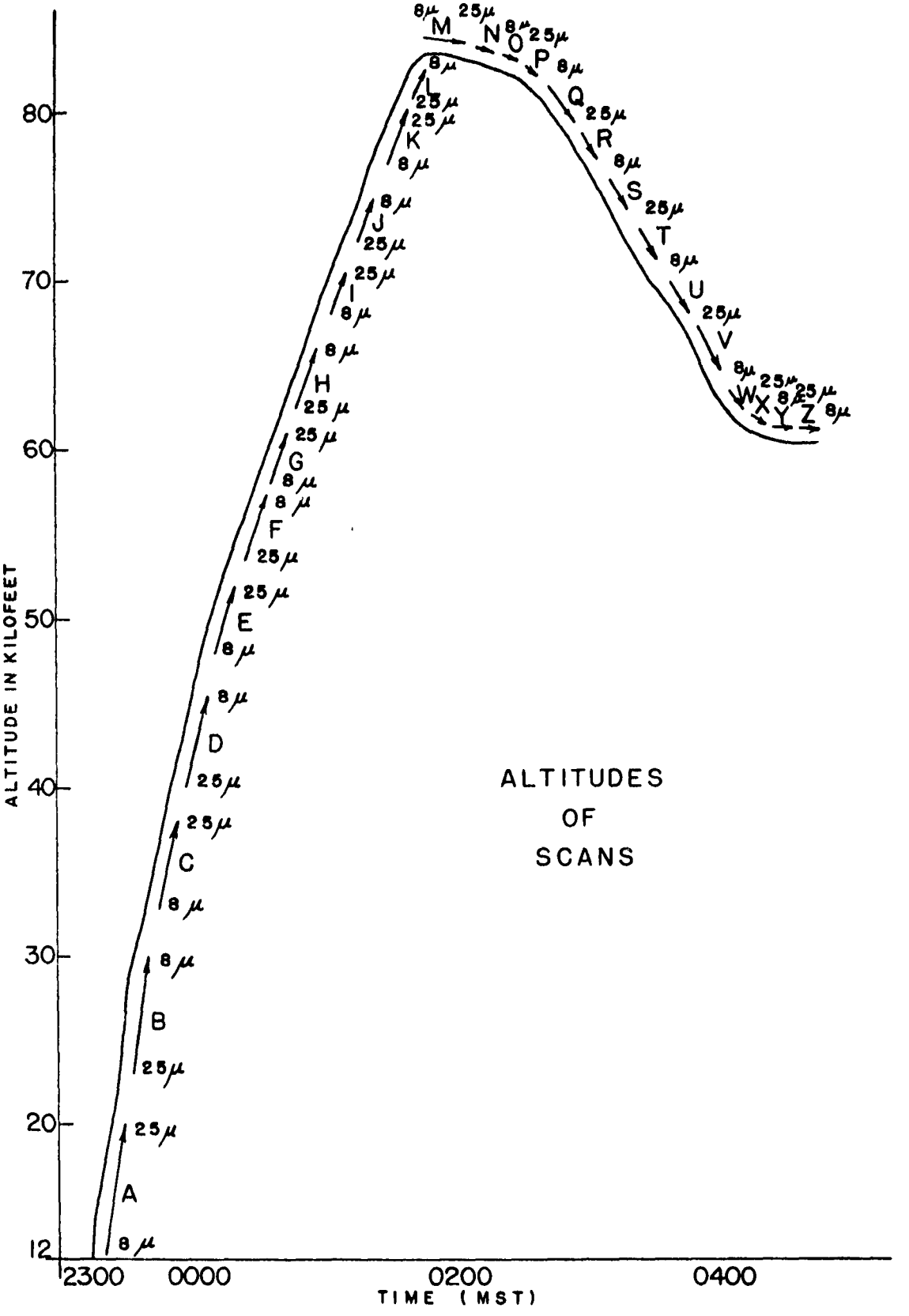
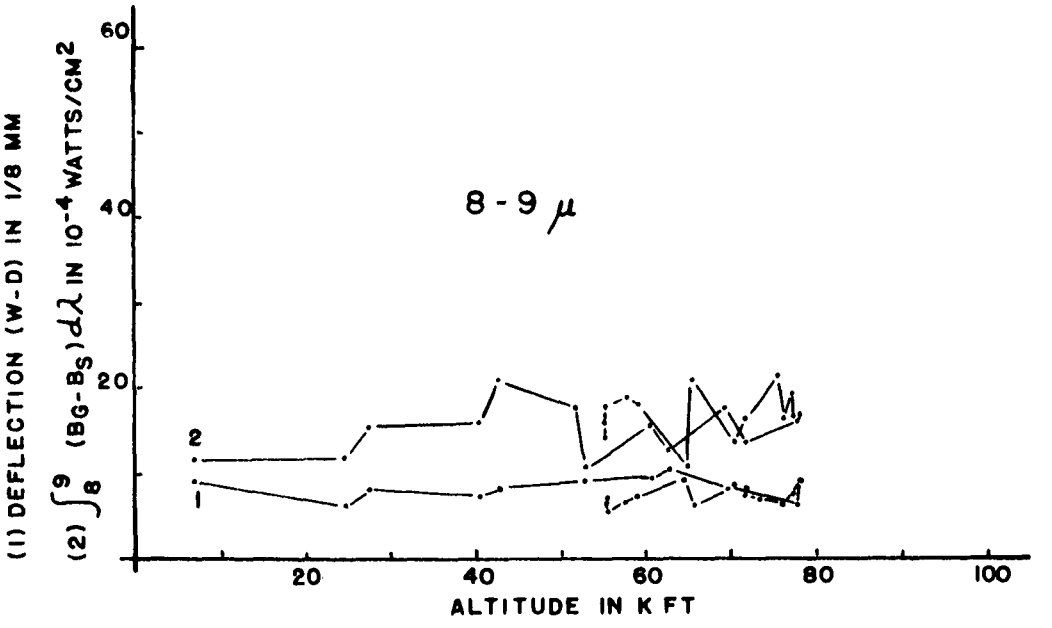

ALTITUDE IN KILOFEET
80
70
60
50
40
30
20
12
2300
0000
0200
0400
TIME (MST)
ALTITUDES
OF
SCANS
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
Y
Z
8μ
25μ

FIG. 12


(1) DEFLECTION (W-D) IN 1/8 MM
(2) $\int_8^9 (B_G - B_S) d\lambda$ IN 10^{-4} WATTS/CM^2
8 - 9 μ
60
40
20
2
1
20
40
60
80
100
ALTITUDE IN K FT

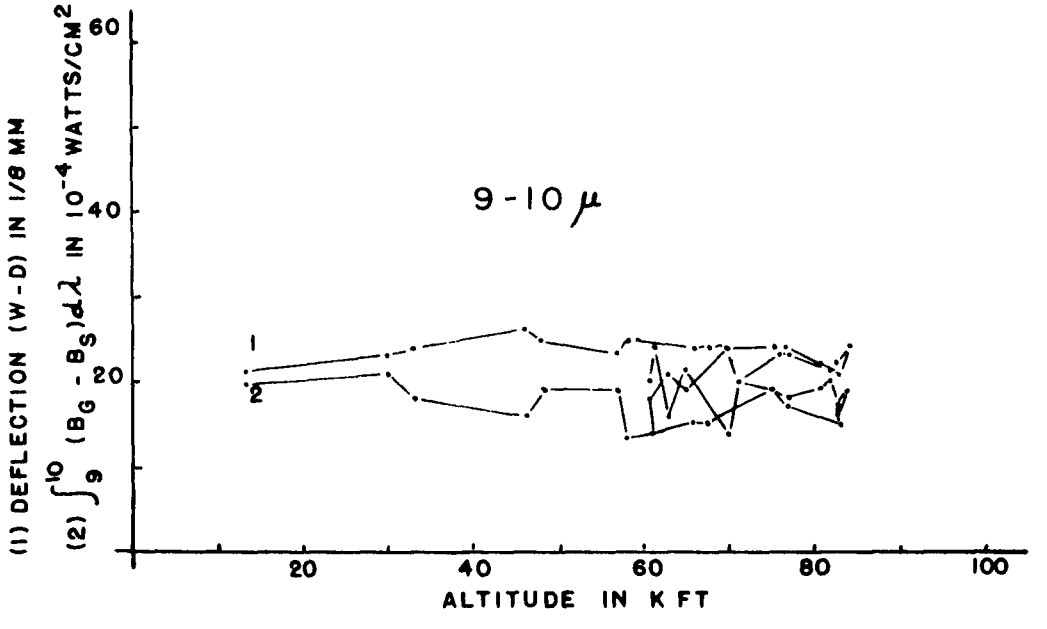
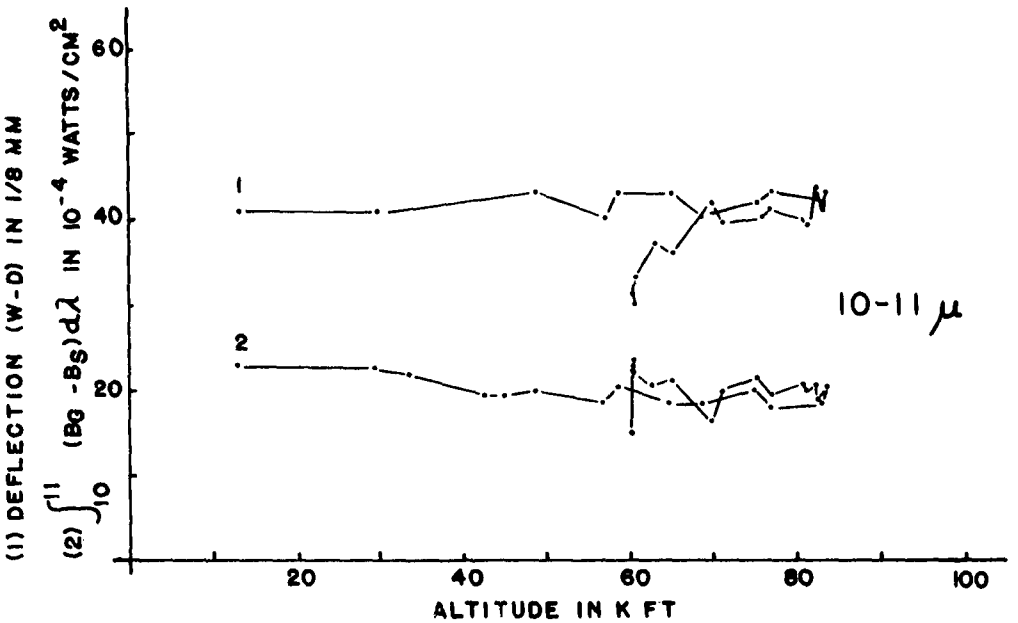

(1) DEFLECTION (W-D) IN 1/8 MM
(2) $\int_9^{10} (B_G - B_S) d\lambda$ IN 10^{-4} WATTS/CM^2
9 - 10 μ
60
40
20
1
2
20
40
60
80
100
ALTITUDE IN K FT

FIG. 13


(1) DEFLECTION (W-D) IN 1/8 MM
(2) $\int_{10}^{11} (B_G - B_S) d\lambda$ IN 10^{-4} WATTS/CM^2
60
40
20
1
2
10-11 μ
20
40
60
80
100
ALTITUDE IN K FT

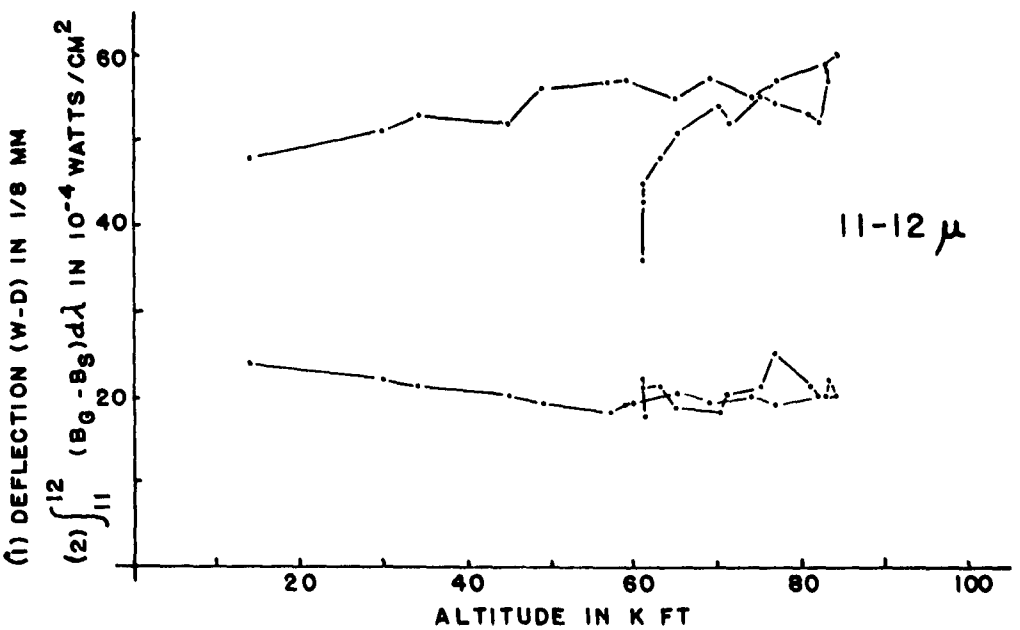
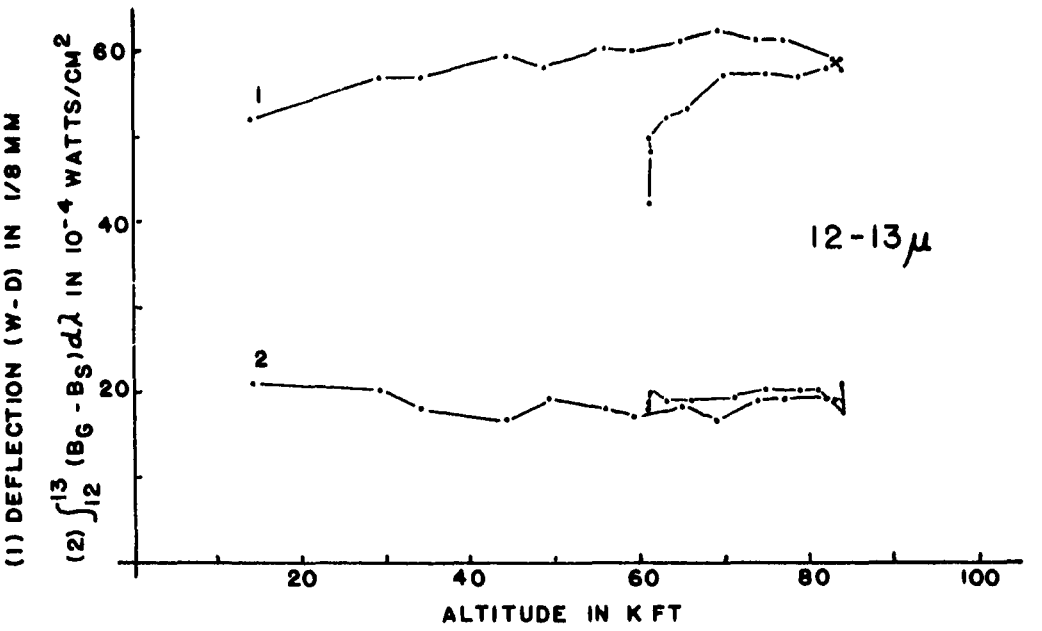

(1) DEFLECTION (W-D) IN 1/8 MM
(2) $\int_{11}^{12} (B_G - B_S) d\lambda$ IN 10^{-4} WATTS/CM^2
60
40
20
11-12 μ
20
40
60
80
100
ALTITUDE IN K FT

FIG. 14


(1) DEFLECTION (W-D) IN 1/8 MM
(2) $\int_{12}^{13} (B_G - B_S) d\lambda$ IN 10^{-4} WATTS/CM^2
60
40
20
1
2
12-13μ
20
40
60
80
100
ALTITUDE IN K FT

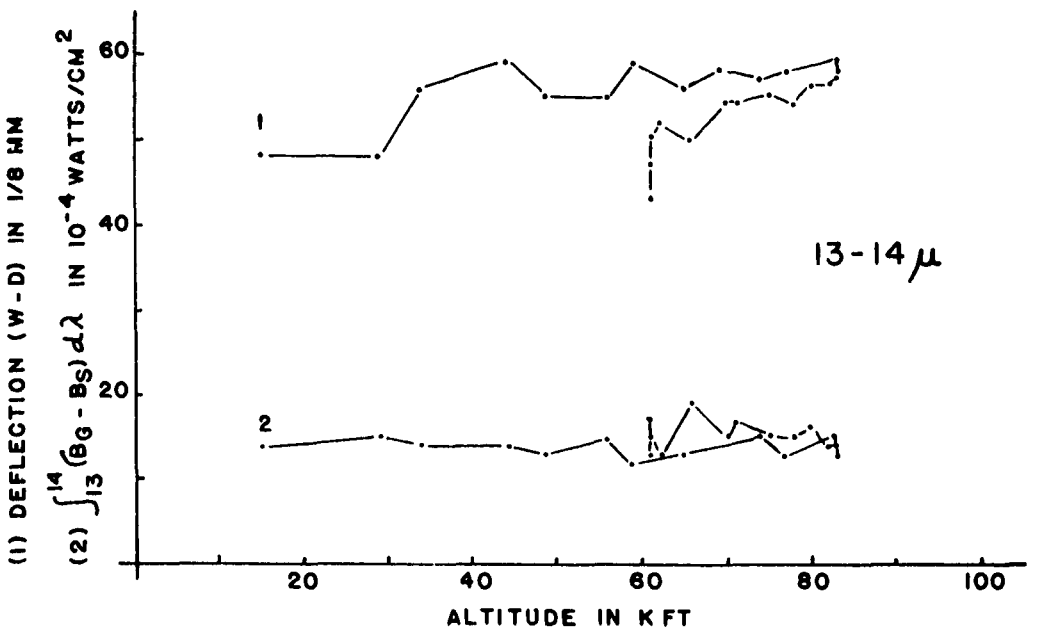
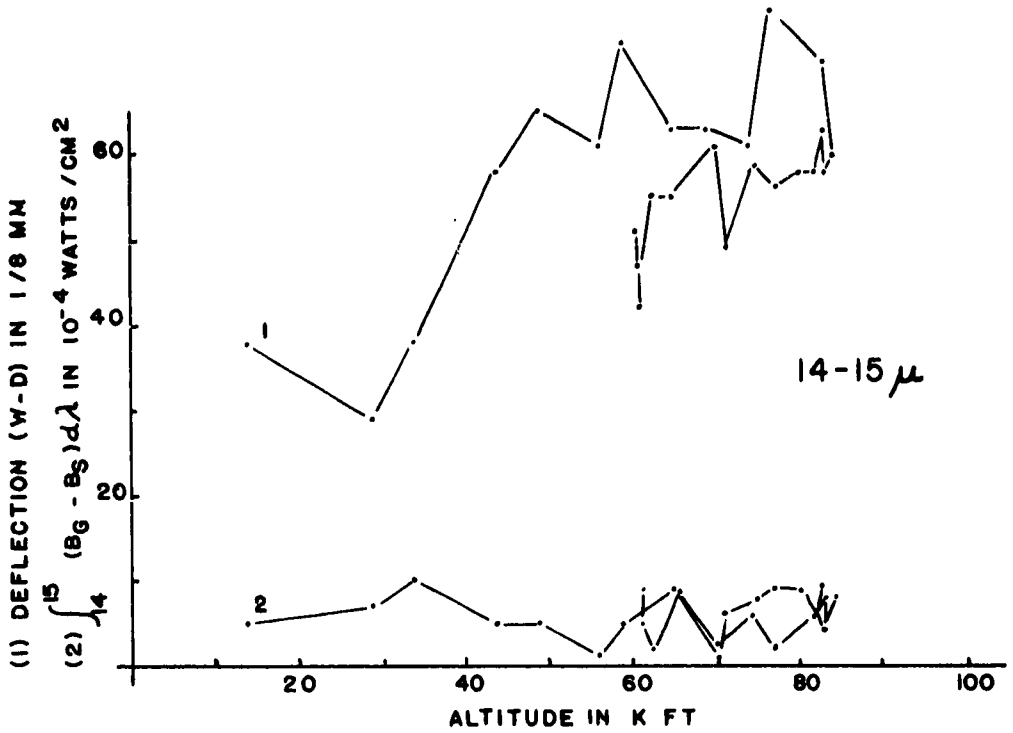

(1) DEFLECTION (W-D) IN 1/8 MM
(2) $\int_{13}^{14} (B_G - B_S) d\lambda$ IN 10^{-4} WATTS/CM^2
60
40
20
1
2
13-14μ
20
40
60
80
100
ALTITUDE IN K FT

FIG. 15


(1) DEFLECTION (W-D) IN 1/8 MM
(2) $\int_{14}^{15} (B_G - B_S) d\lambda$ IN 10^{-4} WATTS/CM^2
60
40
20
1
2
14-15 μ
20
40
60
80
100
ALTITUDE IN K FT

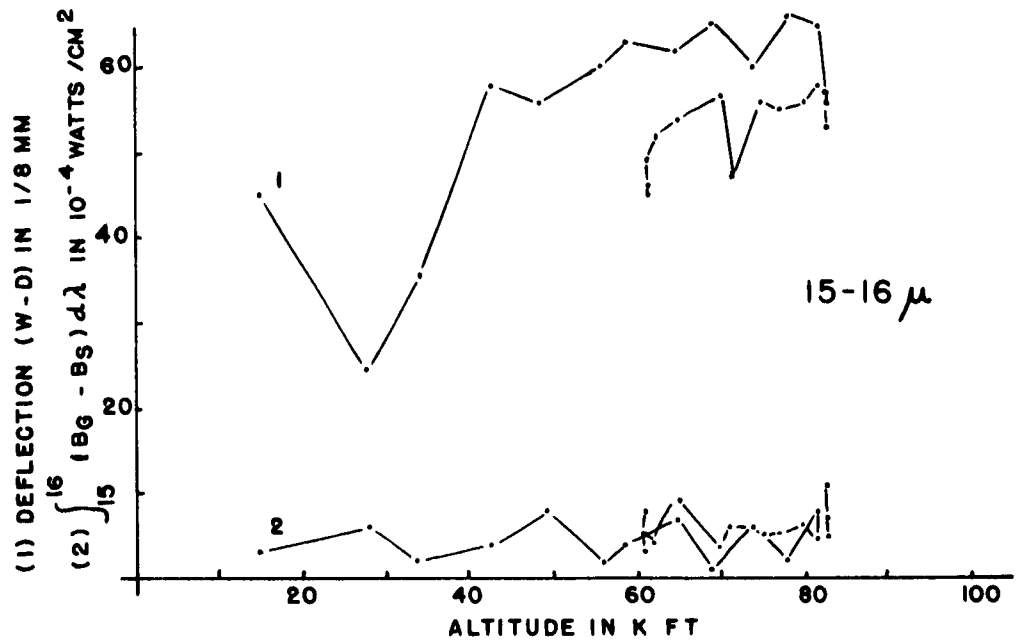
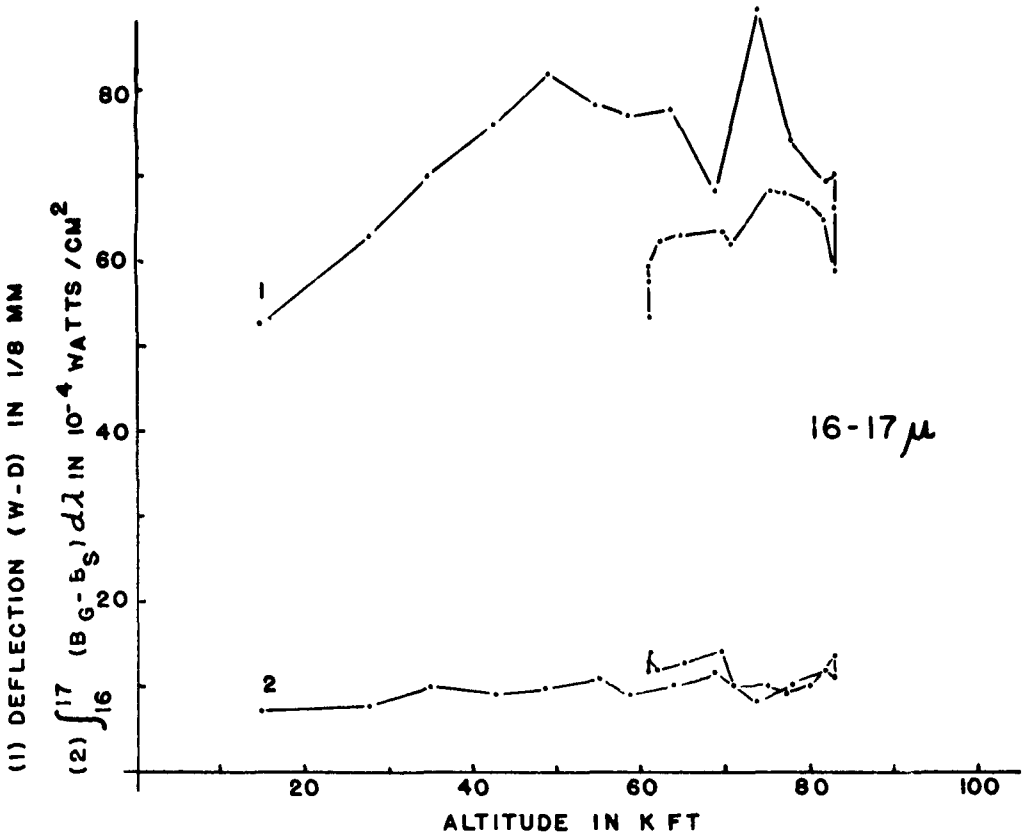

(1) DEFLECTION (W-D) IN 1/8 MM
(2) $\int_{15}^{16} (B_G - B_S) d\lambda$ IN 10^{-4} WATTS/CM^2
60
40
20
1
2
15-16 μ
20
40
60
80
100
ALTITUDE IN K FT

FIG. 16


(1) DEFLECTION (W-D) IN 1/8 MM
(2) $\int_{16}^{17} (B_G - B_S)\, d\lambda$ IN 10^{-4} WATTS/CM^2
80
60
40
20
1
2
16-17 μ
20
40
60
80
100
ALTITUDE IN K FT

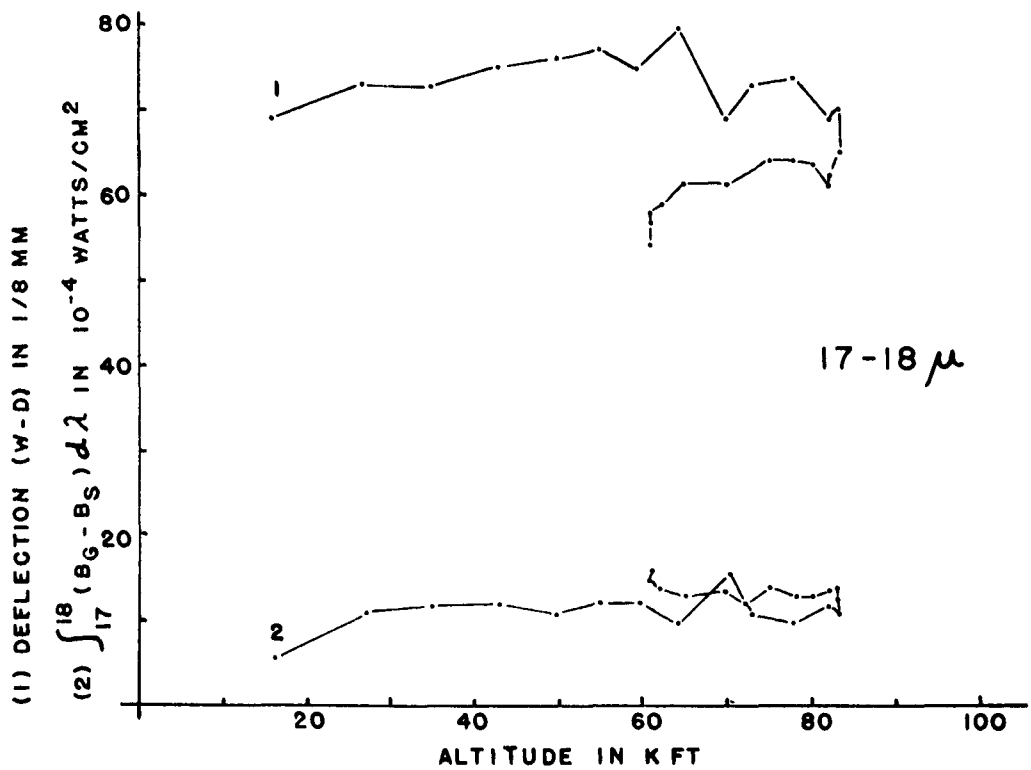
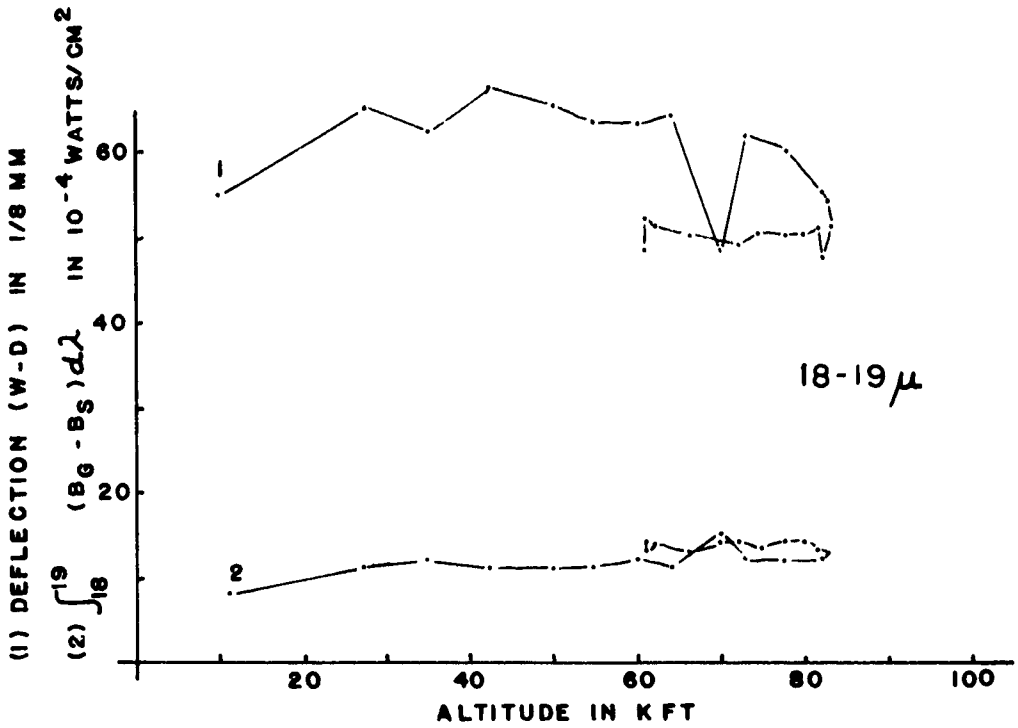

(1) DEFLECTION (W-D) IN 1/8 MM
(2) $\int_{17}^{18} (B_G - B_S)\, d\lambda$ IN 10^{-4} WATTS/CM^2
80
60
40
20
1
2
17-18 μ
20
40
60
80
100
ALTITUDE IN K FT

FIG. 17


(1) DEFLECTION (W-D) IN 1/8 MM
(2) $\int_{18}^{19} (B_G - B_S)\, d\lambda$ IN 10^{-4} WATTS/CM^2
60
40
20
1
2
18-19 μ
20
40
60
80
100
ALTITUDE IN K FT

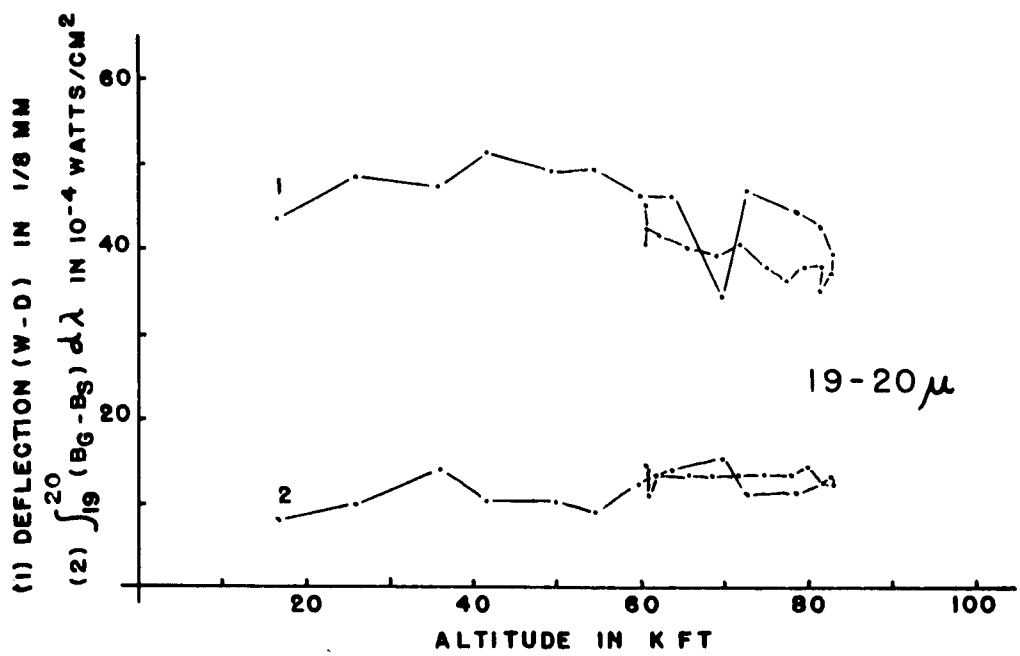
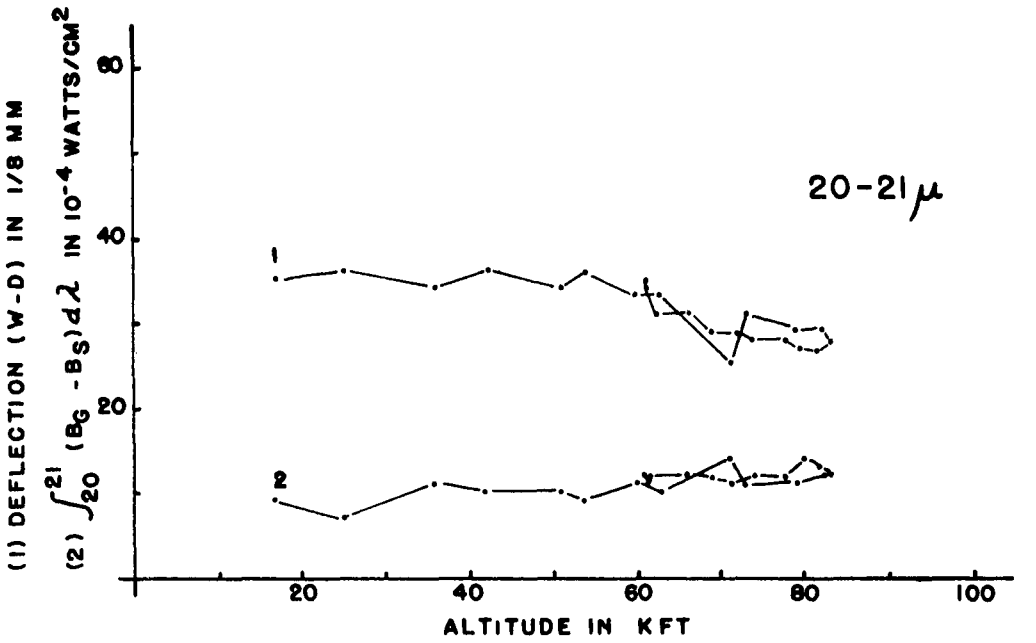

(1) DEFLECTION (W-D) IN 1/8 MM
(2) $\int_{19}^{20} (B_G - B_S)\, d\lambda$ IN 10^{-4} WATTS/CM^2
60
40
20
1
2
19-20 μ
20
40
60
80
100
ALTITUDE IN K FT

FIG. 18


(1) DEFLECTION (W-D) IN 1/8 MM
(2) $\int_{20}^{21} (B_G - B_S) d\lambda$ IN 10^{-4} WATTS/CM^2
20-21 μ
1
2
0
20
40
60
80
100
ALTITUDE IN KFT

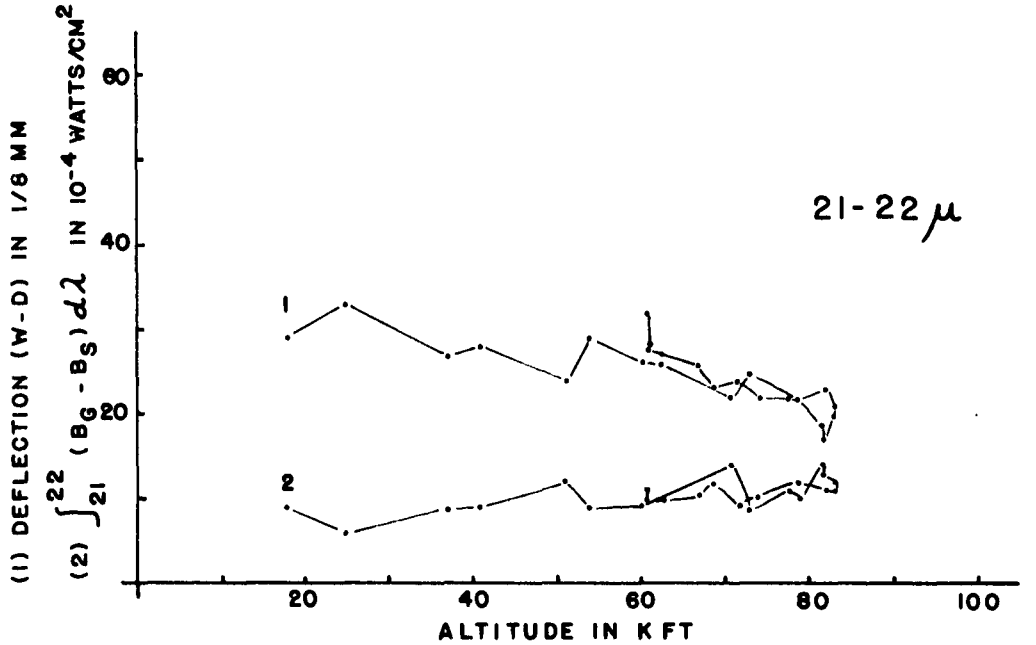

(1) DEFLECTION (W-D) IN 1/8 MM
(2) $\int_{21}^{22} (B_G - B_S) d\lambda$ IN 10^{-4} WATTS/CM^2
21-22 μ
1
2
0
20
40
60
80
100
ALTITUDE IN KFT

FIG. 19

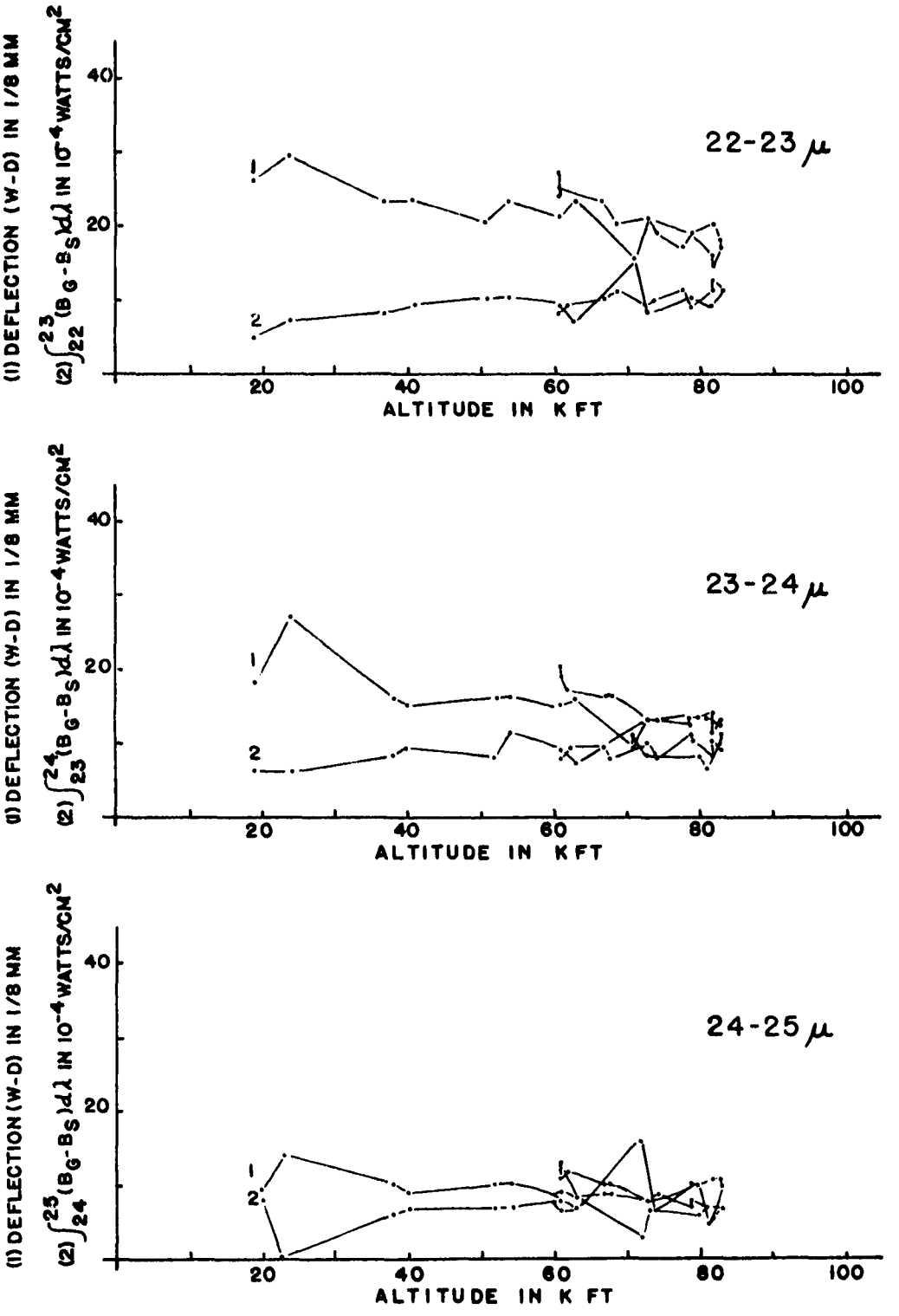

(1) DEFLECTION (W-D) IN 1/8 MM
(2) $\int_{22}^{23}(B_G - B_S)d\lambda$ IN 10^{-4} WATTS/CM^2
22-23 μ
1
2
40
20
20
40
60
80
100
ALTITUDE IN K FT
(1) DEFLECTION (W-D) IN 1/8 MM
(2) $\int_{23}^{24}(B_G - B_S)d\lambda$ IN 10^{-4} WATTS/CM^2
23-24 μ
1
2
40
20
20
40
60
80
100
ALTITUDE IN K FT
(1) DEFLECTION (W-D) IN 1/8 MM
(2) $\int_{24}^{25}(B_G - B_S)d\lambda$ IN 10^{-4} WATTS/CM^2
24-25 μ
1
2
40
20
20
40
60
80
100
ALTITUDE IN K FT

FIG. 20

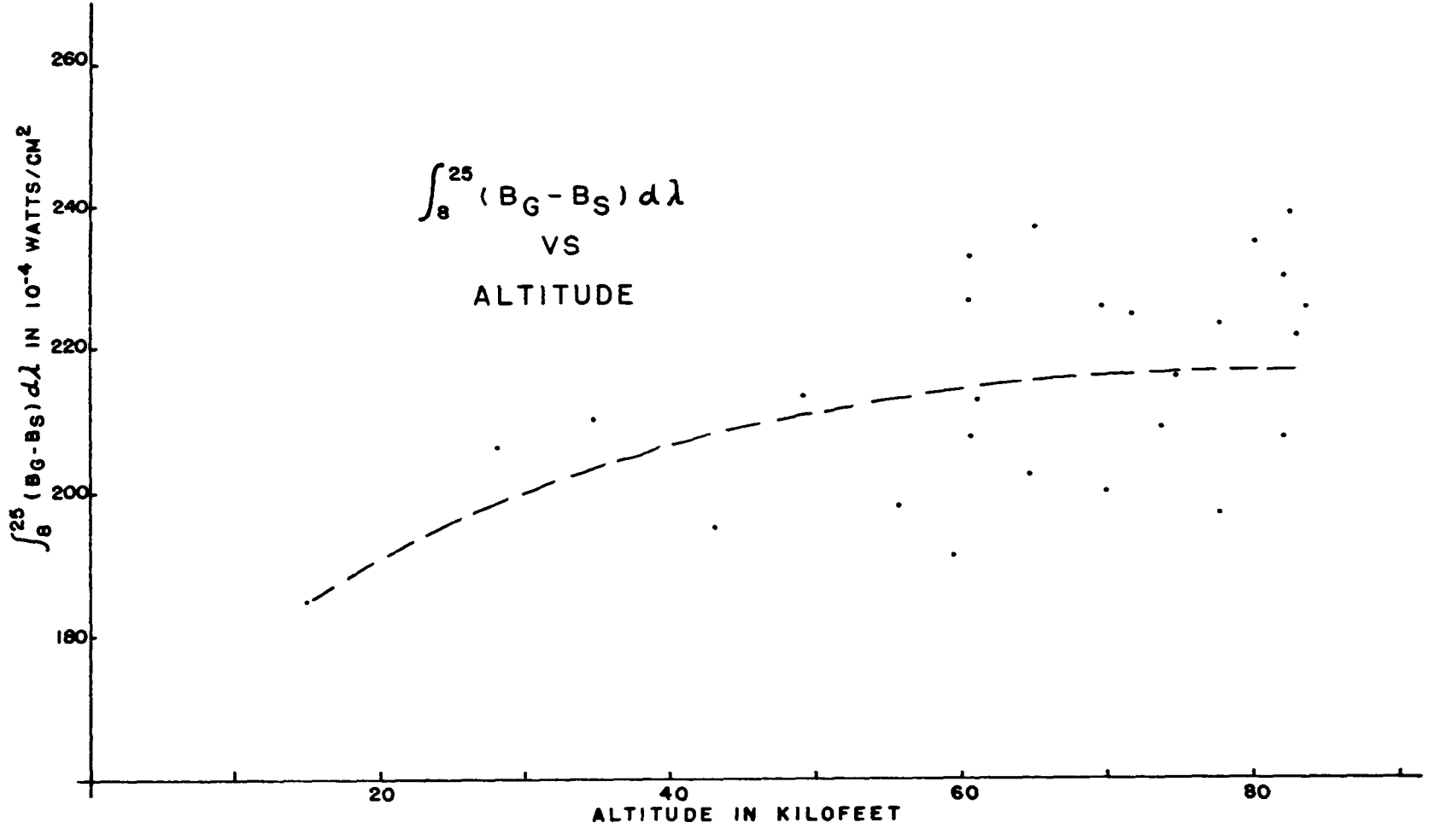

$\int_8^{25} (B_G - B_S)\, d\lambda$
VS
ALTITUDE
$\int_8^{25} (B_G - B_S)\, d\lambda$ IN 10^{-4} WATTS/CM^2
260
240
220
200
180
20
40
60
80
ALTITUDE IN KILOFEET

FIG. 21

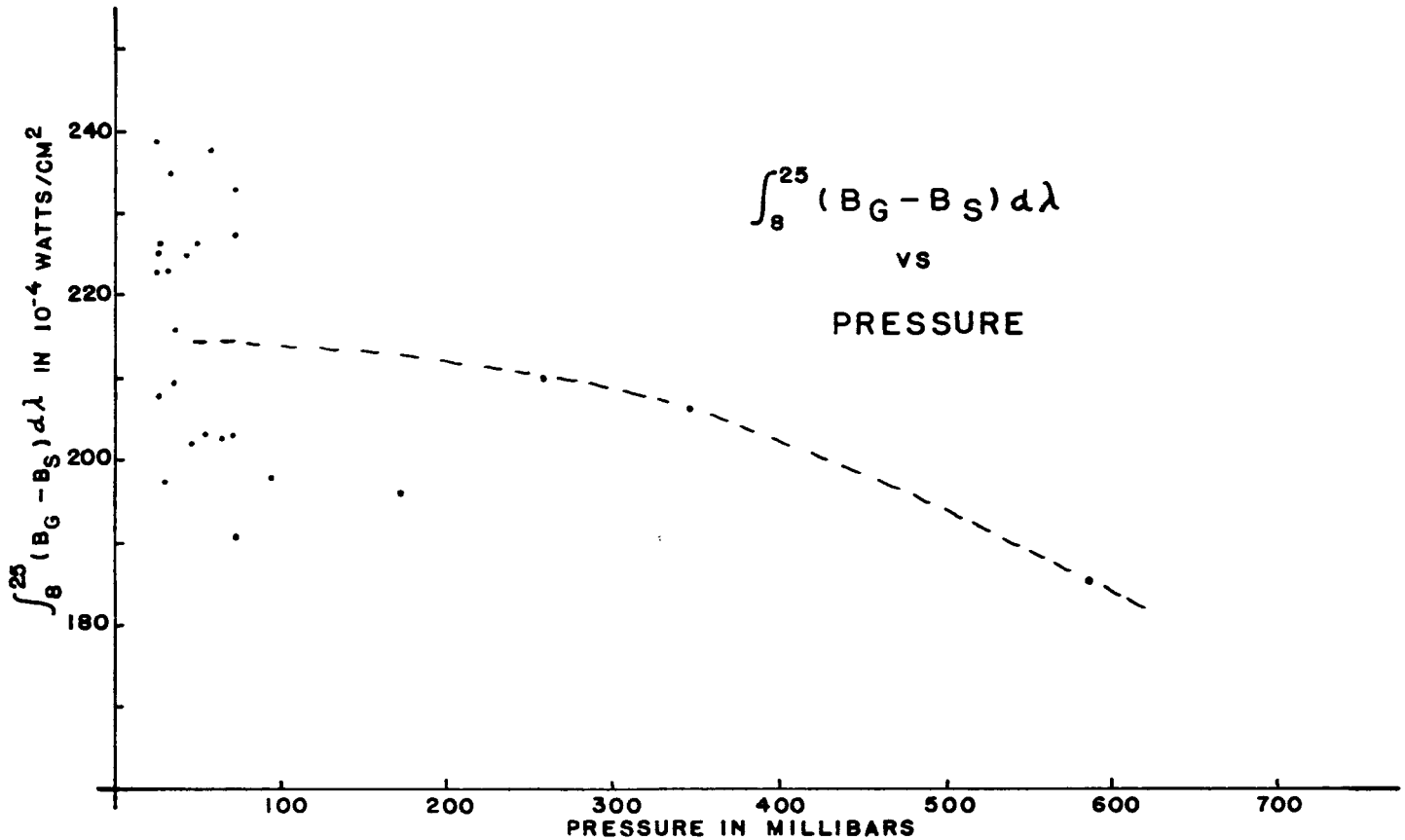

$\int_8^{25}(B_G - B_S)\,d\lambda$
VS
PRESSURE
$\int_8^{25}(B_G - B_S)\,d\lambda$ IN 10^{-4} WATTS/CM^2
240
220
200
180
100
200
300
400
500
600
700
PRESSURE IN MILLIBARS

FIG. 22

Appendix

Publication under Contract AF 19(604)-6174:

White, R. C. and J. Strong, "Sky Radiations from the Balloon Flight of March 8, 1960." Scientific Report No. 1, AFCRL-450, Feb. 1, 1961.

Publications in whole or in part under Contract AF 19(604)-2238:

Strong, John, "Balloon Observations of Earth Radiations in the Infrared - II." Scientific Report No. 1, AFCRC-TN-58-608, Oct. 7, 1958.

Strong, John, "Balloon Observations of Earth Radiations in the Infrared - III." Final Report, AFCRC-TN-59-294, Oct. 15, 1959.

Strong, John and G. A. Vanasse, "Lamellar Grating Far-Infrared Interferometer." J. Opt. Soc. Am. 50, 113 (1960).

Publications in whole or in part under Contract AF 19(604)-949:

Greenler, R. G., "Interference Filters for the Infrared." J. Opt. Soc. Am. 47, 130 (1957).

Greenler, R. G., "Un Spectromètre Interférentiel Fabry-Perot pour L'Infra-Rouge." J. phys. radium 19, 375 (1958).

Newman, J. B., "An Infrared Radiosonde." Scientific Report No. 1, AFCRC-TN-57-492, Aug. 15, 1956.

Strong, John, Balloon Observations of Earth Radiations in the Infrared." Final Report, AFCRC-TR-57-238, Oct. 1, 1957.

Professional personnel who worked on AF 19(604)-6174 project:

Dr. John Strong
Mr. John F. McClellan
Mr. Robert C. White

AF Cambridge Research Laboratories, Bedford, Mass. Office of Aerospace Research
MEASUREMENT OF INFRARED SPECTRAL COMPONENTS FLOWING UPWARD AND DOWNWARD IN THE ATMOSPHERE, by R. C. White, Final Report, April 1963. 6 pp., illus.
AFCRL-63-495 Unclassified report

Raw data of a balloon flight to determine the spectral components of infrared radiation, flowing up and downward in the atmosphere, has been previously reported. This report presents the analysis of that data, giving the flux quantitatively, in the infrared bands (each one micron wide) extending from 3 to 25 microns. Flux upward and downward at various altitudes is given.

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1. Meteorology and Climatology
2. Meteorology
3. Infrared Spectroscopy

I. Project No. 5043
II. Task No. 79708
III. Contract No. AF 19(604)-6174
IV. Johns Hopkins University, Baltimore, Maryland
V. White, R. C.
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